TASK 1
TECHNICAL WORK IN THE AREA OF FACSIMILE

SUBTASK 5
HIGH FREQUENCY (HF) RADIO FACSIMILE

FINAL REPORT
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1 INTRODUCTION

This document summarizes work performed by Delta Information Systems, Inc. (DIS) for the National Communications System (NCS), Office of Technology and Standards. This office is responsible for the management of the Federal Telecommunication Standards Program, which develops telecommunication standards, whose use is mandatory for all Federal departments and agencies. The purpose of this project, performed under Task 1, Subtask 5 of contract number DCA100-91-C-0031 during Option Year 4, was to continue the development of a standard for gray scale image transmission using High Frequency (HF) radio links.

The amateur radio community is presently using a de facto standard to transmit facsimile images using HF radio. This de facto standard is called Fax-480 and it was advanced by Ralph E. Taggart in the amateur radio publication QST. Fax-480 uses an analog frequency modulation technique where black and white pixels are transmitted using subcarrier frequencies of 1500 Hz and 2300 Hz, respectively. Gray scale values are represented by subcarrier frequencies between the black and white limits. The Fax-480 format consists of 480 image lines, each comprised of 512 pixels. The images transmitted using this standard typically originate in microcomputers, and are often photographic (continuous tone) images as opposed to bi-level images. The 512 by 480 image size can be displayed with the 640X480 VGA mode available on many personal computers, with room on the screen left over for menu options and other data.

The transmission of facsimile over HF radio has been limited by the lack of an official standard. In an effort to achieve interoperability in this arena, the NCS has a requirement to standardize facsimile transmissions over HF radio, and has been developing this new standard through the TIA TR-29 facsimile committee. A draft standard has been prepared and balloted. As a result of this ballot the draft standard was revised, and as of this writing is out for an industry ballot.

This report comprises three sections. Section 1.0 provides a brief description of the objectives of the task and an outline of the contents of this report. Section 2.0 is a technical discussion of the issues involved in transmitting a facsimile over HF amateur radio. Section 3.0 provides conclusions and recommendations.

2 TECHNICAL DISCUSSION

2.1 HF FAX Background

2.1.1 Previously Adopted Approaches

Although facsimile is the oldest form of image-transmission technology, it is one of the least used forms of communications in the Amateur Radio Service. Instead, image communications are primarily based on slow-scan television (SSTV) on the HF bands (up to 30 MHz) and fast-scan on the UHF bands (430 MHz and up). This has been due to the relatively limited access to affordable facsimile equipment compatible with the narrow bandwidth available to the amateur radio service in the HF bands. Typical FAX communication stations employed mechanically driven drums with electronics providing the drive signals for the synchronous motors, and used an intensity modulated lamp focused on the drum containing light sensitive paper in the receiver.

Over the years advances in wirephoto systems led to older surplus equipment becoming available but with constantly changing line rates and image formats. Line rates varied from 60 LPM to 480 LPM. The low line rates tended to be incompatible with the Amateur Radio Service, as station identification is required at least every ten minutes. The higher line rates required too wide a bandwidth. This equipment was difficult to maintain, and it required special paper and lamps for continued operation, all of which contributed to the limited appeal of facsimile as a communication mode.

The current wide availability of Group 3 facsimile equipment may be of use on the VHF or UHF bands, but is unsuitable for HF (narrow) band operation due to the wider bandwidth required by the digital transmission mode.

2.1.2 Lack of Standards

It is the lack of standards, within the context of an easily implemented system utilizing the HF bands, that has stymied the Amateur Radio Service=s use of facsimile. When the budget constraints of amateur stations are also considered, it becomes evident that existing facsimile standards are incompatible with the objectives of the Service.

2.2 Issues

2.2.1 Transmitter Bandwidth vs. Transmission Time

Two requirements must be addressed by any proposed HF radio facsimile standard. The first is the need to operate within approximately 2.5 kHz of audio transmission bandwidth, transmitted using an AM (SSB) technique. The second requirement is to keep the transmission time per image to a reasonably short time, both for station identification purposes and to allow for the propagation, interference, and

operational realities of HF radio communications.

2.2.2 Transmission Concerns

Operating in the HF bands in general is difficult due to the unpredictable nature of propagation. Long distance communication is the result of refraction of radio waves by the ionosphere. Changes in the ionosphere throughout the day make communications capability vary from nonexistent to excellent on any particular band. Solar activity, multipath interference, and local electrical noise also add to the problem. Adjacent channel interference within the Amateur Radio Service is another problem that occurs. It is as severe or worse than the natural conditions. Operation in the amateur bands is not channelized. Often, multiple transmissions on adjacent frequencies result in overlap of some of the modulation frequencies. Communications may have started with each station unaware of the other but over time the propagation path is established and worsening interference results. This interference is a major problem with operation in the crowded amateur HF bands. Transmission should therefore be kept reasonably short to allow for signal reports to be exchanged often.

2.2.3 Digital vs. Analog Tradeoffs

PART 97 of the Federal Communications Commission (FCC) Rules and Regulations allow image transmission using essentially any modulation method, within the specific limitations of operating bands. Quantized or digital information is permitted for the signal modulating the main carrier. This opens the possibility of replacing the older analog-based transmission techniques with digital techniques. Digital transmission on HF frequencies must occupy, by regulations, no more bandwidth than the nominal 3 kHz audio bandwidth used for voice transmissions. This rule suggests that digital image transmissions of up to 2400 bit/s are possible.

Part 97.307, subparagraph (f)(3) of the FCC rules restricts Adata emission using a specified code@ to 300 bauds in the HF bands. This limit refers to the transmission of data and radioteletype (RTTY) only. If a transmission includes solely image data, however, the rules allow the use of *any* data transmission mode with no baud restriction as long as the image data is kept within the 3 kHz bandwidth limit. The data modes used to transmit the image data can include RTTY or any other HF data transmission technique.

Since quantized image data transmission is permissible, adopting a modern image compression technique such as JPEG (Joint Photographic Experts Group) might reduce the time required for transmission, but only when operating with a perfect circuit. In practice, the high bit error rate that results in HF radio modems would require the adoption of some sort of error recovery since the compressed digital data stream must be delivered errorlessly to achieve proper decoding. Uncorrected errors result in

severe multi-line distortions. Adding forward error correcting techniques is counter productive from two standpoints. First, the added overhead is incompatible with the desire to minimize transmission time. Second, forward error correcting algorithms reach the point of diminishing returns with respect to coding gain as the bit error rate of the circuit approaches 10^{-2}, a common situation in HF circuits.

Amateurs currently use the Amateur Teleprinting Over Radio (AMTOR) data transmission mode, which is derived from the Maritime Mobile Service SITOR system. AMTOR Mode A uses an Automatic Repeat Request (ARQ) protocol. It is also transmitted at the 300 baud rate. It uses the 5-bit (BAUDOT) ITA2 code with two additional bits added to maintain a constant ratio of four marks to three spaces. The constant bit ratio facilitates error detection. Unfortunately, the added bits increase the length of the code and thus make it undesirable for the transfer of quantized image data.

Another possibility is the use of packetized transmissions, but this approach also must comply with the 300 baud restriction. Packet transmission is already in use by the Amateur Radio Service. A Draft Recommendation for HF Facsimile for Maritime Mobile Users, has been evaluated in this light, but requires a data modem capable of 1000 bit/s (exceeds 300 baud restriction) and the use of gateways.

The proposed HF-Facsimile standard (See the Appendix) is based on an analog transmission technique. It uses an FM modulated audio subcarrier. FM reduces the problems that fading of the signal during long distance transmission would cause if direct AM modulation were used. The fades would result in the grey level variations throughout the image. The resulting audio signal can be directly interfaced to the microphone input and speaker audio output of the radio transceiver.

2.2.4 Modern Equipment Available

The most significant addition to Amateur Radio Service stations of late has been the personal computer. These have been applied not only for record keeping functions, but also to provide real-time tracking of Amateur communication satellites, antenna pointing, and packetized digital data communications. As the multimedia explosion continues to drive down the price of image capturing devices, computers have become a new resource for use in higher resolution HF facsimile transmission.

This presents an excellent opportunity to replace the mechanical equipment previously associated with facsimile with the display and various sources of image data available to the personal computer. The extremely simple and low cost interface required to connect the HF radio to a personal computer using the recommended standard will promote wider use and exploration of this form of image transmission.

2.3 Status

The proposed draft HF radio facsimile standard is included in the Appendix. The proposed standard builds on the current de facto standard in use in HF radios in the Amateur Radio Service using an analog transmission technique. Transmission bandwidth restrictions and the short time per image that is desired do not favor digital data transmission. The recommended approach transmits an image in approximately two minutes 18 seconds.

The proposed standard also takes advantage of video standards, monitor resolutions, and image file formats. The recommended format represents a unique combination of readily available VGA equipment characteristics (640 pixels x 480 lines x 16 gray levels) and timing derived from a simple binary countdown of a readily available precision reference frequency. The resulting 512 pixels x 480 lines generate a square aspect ratio on the display and conveniently leave an area to the side of the screen for status display and command inputs. This simplifies software development by eliminating overlays and windows. The line format provides a 1:1 relationship between pixel and sample clock. Therefore software overhead is reduced, and no scaling or interpolation is required.

The recommended format represents a significant increase in horizontal and vertical resolution over previously used facsimile and SSTV formats. Note that the pixel clock of 1952.125 Hz is faster than the individual subcarrier frequencies which transfer the information. There will be some reduction in resolution from the actual 512 pixels. The response time of the receiving audio frequency discriminator is the primary determining factor. However, the most noticeable increase in resolution comes in the vertical scan direction with twice the number of lines available. This increased resolution should promote wider use and exploration of applications.

The similarities and differences between the de facto FAX-480 standard and the TIA TR-29 draft standard are summarized in Table 1.

TABLE 1 - COMPARISON OF STANDARDS

Specifications	FAX-480	TR-29 Draft Standard
Image aspect ratio	1:1	1:1
Image size (pixels)	512 x 480	512 x 480
Direction of horizontal scan	left to right	left to right
Direction of vertical scan	top to bottom	top to bottom
Pixel clock	1953.125 Hz	1953.125 Hz
Pixel clock accuracy	not specified	25 ppm
Synchronization frequency	1200 Hz	1200 Hz
Black frequency	1500 Hz	1500 Hz
White frequency	2300 Hz	2300 Hz
Gray Scale representation	range of frequencies between black & white	range of frequencies between black & white
Line synchronization	5.12 ms of 1200 Hz	5.12 ms of 1200 Hz
Frame start signal	black and white frequencies alternate every 2.048 ms	black and white frequencies alternate every 2.048 ms
Number of phasing lines	20	20
Phasing line format	10 clock cycles of sync & 512 clock cycles of white	10 clock cycles of black & 512 clock cycles of white

As of this writing, the draft standard is out for an industry ballot. When approved, it will become a TIA/ANSI standard.

2.4 Outstanding Issues

High resolution (150 dots per inch and above) image transfer may be possible with only a moderate increase in transmission time if JPEG type compression techniques are employed. The amount of compression and the ability to enhance the radio link with the application of Digital Signal Processing (DSP) techniques could combine to make an all digital approach viable. The DSP contribution could be in the

area of removing adjacent channel interference and in-band heterodyne signals. Regulatory restrictions based on the type of radio service used need to be further explored as well.

3 RECOMMENDATIONS

It is recommended that additional study be given to the area of using digital communications in the HF bands for transmitting images. With the increasing popularity of packet data communication modes, the very low cost of widely available terminal node controllers (TNCs) placed between the HF radio and the personal computer is actually less than implementing the proposed analog-based approach. Where stations already have established digital capability, image communication may be possible with the addition of application software.

In addition to the HF bands, there is a tremendous ability in the Amateur Radio Service to link widely separated geographical sites using VHF and UHF repeaters. These include Digital Repeaters. To promote interoperability, further investigations should include these bands as well. The VHF/UHF bands are characterized by better communications reliability and wider bandwidth.

REFERENCES:

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Appendix

HF Radio Facsimile Draft Standard